Development of Emissions Inventories for Ammonia in Agricultural Systems of California

A Proposal Submitted to the
State of California Air Resources Board

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Purpose

The primary purpose of this proposal is to present a comprehensive plan to assess major agricultural sources of ammonia (NH_3) gas emissions at a state-wide level, with special focus on the Central Valley of California. Background data synthesis and analysis requirements are described. Techniques are reviewed for the design and testing of field emission measurements of NH_3 from fertilizer (chemical and organic) and soil sources in the Central Valley. Simulation modeling approaches for NH_3 emissions are outlined as a means to integrate mechanistic understanding of measured controls on trace gas fluxes. Potential use of a geographic information system (GIS) is described in combination with the prototype simulation model to extrapolate state-wide NH_3 emission estimates for all areas of California.

Objectives

As focus for the research and assessment activities to follow, we submit the following objectives:

Objective 1: Determine the major agricultural field sources of ammonia emissions in the Central Valley of California.

Objective 2: Determine seasonal flux rates of ammonia from agricultural field sources in the Central Valley of California.

Objective 3.. Determine the regional budget of annual ammonia emissions from soil sources over the state of California.

Background

Ammonia is the dominant gaseous base in the atmosphere and a principal neutralizing agent for atmospheric acids. The supply of alkaline soil dust and gaseous NH_3 available in the atmosphere may control the acidity of precipitation. Nevertheless, NH_3 remains one of the least well characterized atmospheric trace compounds. This situation persists as a result of several factors: experimental difficulties associated with NH_3 measurements, rapid gas-to-particle conversion of NH_3 in the atmosphere, capacity of soils, organic matter, and vegetation to act as both source and sink for atmospheric NH_3, and variability in nitrogen fertilizer management (Langford, 1992).

There is a limited amount of published information from which to develop direct emissions estimates of NH_3 for the State of California in general, and the Central Valley in particular. Estimated patterns of nitrogen deposition suggest that, for California locations close to photochemical smog source areas, concentrations of oxidized forms of N (NO_2, HNO_3, PAN) dominate, while in areas near agricultural activities the importance of reduced N forms (NH_3 and NH_4^+) increases significantly (Bytnerowicz and Fenn, 1996). However, the magnitude and distribution of current NH_3 emissions from fertilizer and other agricultural sources is still largely undetermined (Matthews, 1994).

The conditions favoring soil NH_3 emissions from chemical fertilizers have been documented to a limited degree. High soil pH (7-9) is generally associated with high NH_3 volatilization, although losses can occur from acid as well as from alkaline soils, due to elevated pH and NH_4^+ concentrations at "microsites" where surface-applied urea ($CO[NH_2]_2$) fertilizer particles dissolve and hydrolyze (Fenn and Richards, 1986). Microsite formation of ammonium carbonate ($NH_4^+ HCO_3^-$) by the microbial enzyme urease can promote high volatilization losses.

Soil wetting patterns can strongly affect NH_3 losses. Volatilization rates are typically diminished when urea can be transported rapidly to deeper soil layers (Fenn and Miyamoto, 1979). Field studies suggest that merely delaying urea application for a few hours to avoid accumulation at wet soil surfaces may be a practical way to reduce NH_3 volatilization in humid areas (Priebe and Blackmer, 1989). Natural winter snow cover and cold temperatures can decrease airborne soil dust and possibly the evolution of NH_3 from some grassland soils (Munger, 1982).

Methods of fertilizer application and tillage also have notable impacts on trace gas loss. The potential for NH_3 volatilization loss is high where surface application of nitrogen is combined with no-till management (Fox and Piekielek, 1987). Broadcast or band application results in fertilizer particles that aggregate or lie contiguously with adjacent particles (Hauck, 1981). Aggregation of fertilizer particles with increasing broadcast application may lead to higher nitrification potential and NO_2^- accumulation in acid soils. Conversely, high rates of band-applied anhydrous ammonium in more alkaline soils may retard nitrification for many days; N oxidizing reactions may increase as heavy moisture input or mass particle movement subsequently dilutes the fertilizer-soil microsite reaction zone.

In addition to chemical fertilizer sources, loss of NH_3 from organic manures and compost has been studied using micro-meteorological mass balance and small wind tunnel experiments, mainly for the purposes of odor control and animal health. It appears that ammonia can be produced from manure via both biological and chemical pathways. Reports indicate that up to about 25% of the total manure nitrogen could be volatilized as NH_3 over a several week period, and that changes in pH (>7.5) had the most significant effect on the abiotically induced ammonia emissions (Dewes, 1996). Irrigation immediately after spreading may significantly reduce NH_3 emission from manured plots (Rodhe et a.,

1996). Composting at relatively high temperatures may also reduce NH_3 fluxes. Ammonia volatilization from mulches could be negatively correlated with leaf lignin content, whereas green manures seem to emit little NH_3, on either unlimed and limed soils (Glasener and Palm, 1995).

Statement of Work

We propose a series of tasks below for data gathering, field measurements, and simulation modeling, plus extrapolation of NH_3 emissions from agricultural systems in California's Central Valley and from natural (uncultivated) soils statewide.

Task 1. Data Assimilation and Analysis of Previous NH_3 Emission Estimates

Our background search of the literature has uncovered well over 80 potential publications and reports from which NH_3 fertilizer emissions might be summarized, compared, and compiled into a useful reference data base. We have found approximately 25 citations in the on-line computer listings matching key words for NH_3 emissions and chemical fertilizer management, and more than 60 citations matching key words for NH_3 emissions and organic fertilizer/compost management. In addition, we have located several unpublished reports of NH_3 volatilization flux estimates that are accessible on the World-Wide Web sites of numerous agricultural research organizations. These data on NH_3 emissions must next be entered into a spreadsheet data base, followed by a systematic comparison and synthesis of standardized flux rate estimates for a variety of agricultural systems.

Task 2. Field Measurement Approaches

Based on our extended background research on gas sampling technologies, we describe in this section an approach for design and testing of a two-phase field measurement scheme for soil and fertilizer NH_3 volatilization fluxes. The scheme would build partly on the field sampling protocol developed by Matson and Firestone (1997) for N trace gas emissions in the Central Valley of California. Phase 1 of the scheme would involve estimation of soil NH_3 volatilization rates from chemical fertilizer sources during the Spring-Summer crop growing season in the Valley. Phase 2 would involve estimation of NH_3 emission from manure and organic farm residue sources during the Summer-Fall period before and after residue/slurry application, especially during periods when Valley air temperatures reach peak seasonal levels.

The location of agricultural field sites for these measurements would be on or near the campus of California State University at Fresno (CSUF). These sites are supported and used for research by the Center for Irrigation Technology (CIT) at CSUF. Study areas at CSUF (latitude N 36° 47', longitude W 119° 45') are close to the geographic center of California and occupy a representative part of the San Joaquin River Valley. Fresno County is among the leading counties of the nation in the production of field, seed, fruit, and nut crops. Periodic air quality problems in this part of the Valley may be related to emissions of nitrogen trace gases from fertilized farm sites and animal manure locations.

The farm/laboratory at CSUF includes about 50 Ha of orchard (primarily deciduous stone fruit and citrus), 65 Ha of vineyard (table, raisin and wine grapes), 125 Ha of annual crop land, and 70 Ha for animal units (beef, dairy, sheep, horses and poultry). The soils range from loamy sands (Atwater) through Durixeralfs (San Joaquin) to clays (Hildreth). Irrigation systems include sprinkler, drip, and surface methods. Most of the land is in production sized units for use by the students in various majors and programs but is also available for non-destructive research of this nature. There is a Farm Operations staff to perform the various cultural practices required for the crops. The CIT also has land on the farm/lab to be used for more intensive research than is possible in the commercial type fields. In addition, CIT has a permanent staff for field and laboratory research as well as administration of projects. Both undergraduate and graduate students, most with experience in commercial agriculture and/or research, are available as field assistants.

In terms of field measurements for ammonia emissions, it should be noted that reliable and cost-effective techniques are still under development by the atmospheric chemistry research community. One relatively well-tested method for measuring NH_3 emission fluxes from agricultural field systems is by the gradient diffusion technique (Denmead, 1983). In principle, ammonia fluxes can be determined by simultaneous measurements of the NH_3 concentration gradient and associated heat or momentum flux in the field. The vertical NH_3 concentration gradient in the air is usually measured using acid traps. Several other instruments for measurement of ambient NH_3 concentrations have been used, including denuder sampling with detection by chemiluminescence, ion chromatographic, or colorimetric analysis (Williams et al., 1992).

With proper evaluation, gradient diffusion or mass balance methods eliminate several problems known to exist with small chamber methods for N trace gas measurements, such as those used by Matson and Firestone (1997) for soil NO fluxes. These problems, which are particularly important for NH_3 measurements, include reaction of the trace gas with enclosure surfaces, alteration of the local microclimate and disturbance of the soil by placement of small chambers. A further advantage of these methods for regional emissions inventories is that it can horizontally integrate the large spatial variability characteristic of N trace gas fluxes in the field.

A more sophisticated, and potentially more expensive, prototype field method for measuring ammonia fluxes from agroecosystems is by the eddy correlation technique (Pattey et al., 1992). Eddy correlation is a well-established technique that has the primary advantage of measuring turbulent diffusive fluxes directly across a near-horizontal plane above the field surface. It requires a rigid platform unencumbered by significant aerodynamic obstacles. Vertical wind speed fluctuations and other surface thermal properties are typically measured using a digitized ultrasonic anemometer and a fast-response thermocouple. Mean vertical and horizontal wind speeds are measured with a fast response cup anemometer. Humidity is measured with infrared absorption hygrometer. Together with flux densities of water vapor and heat, chemical fluxes are computed as covariances of the fluctuations of vertical wind velocity with fluctuations of gas concentrations or mixing ratios at the same point and time.

Arguably the most difficult requirement in using eddy-correlation methods to measure fluxes of trace substances is the need for fast-response gas sensors. For example, suitable sensors are in developmental stages for NH_3, N_2O, non-methane hydrocarbons, organic sulfur compounds, and many other species. Ammonia gas analyzers are currently being tested in the field to measure absolute NH_3 concentrations by infrared absorption techniques using a tunable diode laser (TDL) source -- emission lines are "tuned" to minimize the error caused by absorption from interfering gas species. These lasers typically require cooling by liquid nitrogen, which necessitates an intensive maintenance effort. Field techniques using tunable diode lasers for NH_3 measurements are being tested, for example, by G.W. Thurtell and a team from the University of Guelph (Simpson et al., 1996). It appears, however, that based on separate cost estimates provided to us in the past month by two different commercial vendors, fabrication and delivery of a TDL system for NH_3 will be prohibitively expensive to include in this proposal – quoted prices for the TDL range from $160,000 to $210,000 with an estimated delivery time of 6-8 months.

Hence, for this research proposal, we plan instead to use a more economical, readily available, and well-documented mass balance technique (Leuning et al., 1985) to field test estimation of NH_3 emission fluxes in cropped fields at or around the CSUF campus. There are numerous advantages, including low cost and ease of installation, to selecting the mass balance technique for estimating field NH_3 fluxes, especially following fertilizer applications (see discussion in Denmead, 1983). This method

is used generally to compute gas flux rates into the atmosphere from a treated plot area of limited upwind extent, in proportion to the rate at which the gas is transported by the wind across the downwind plot edge. In brief, flux measurements will require relatively low cost acid trap samplers (placed both upwind and downwind of the plot area) to capture the NH_3 gas emissions, precise measurements of wind speed and direction at the plot location, and an ion-selective electrode probe to measure NH_3 concentrations extracted in the laboratory from the acid traps (Leuning et al., 1985).

Some requirements at the plot level are noteworthy at this point...
-- Measurement plot dimensions (i.e., the fetch) should be on the order of only 10-20 meters,
-- Circular plot shapes simplify the corrections for fetch and wind direction,
-- Daily collection and analysis of NH_3 sampler traps is optimal.

We emphasize that this measurement system will be of a experimental nature, requiring careful testing and evaluation before confidence in the reliability of flux measurements can be raised to acceptable levels. Specifications for the field measurement system must be based on previously reported wind speeds and NH_3 flux levels from temperate agricultural systems, for comparison to the ambient NH_3 levels, which is typically on the order of 3 μg NH_3-N m^{-3}. Ammonia flux densities from agricultural systems range from 0.5 to 20 μg NH_3-N m^{-2} s^{-1} (with gas densities between 10 and 600 μg NH_3-N m^{-3}), depending partially on fertilizer rates and forms (Denmead, 1983). Under feedlot conditions, flux densities can exceed levels of 100 μg NH_3-N m^{-2} s^{-1} (with gas densities of 1200 μg NH_3-N m^{-3}).

Phase 1. Spring-Summer - Chemical fertilizer sources of NH_3 from cropped soils.

In testing the mass balance technique for soil gas emissions, we will first target cropping systems for measurements that tend to favor high NH_3 volatilization fluxes. These are typically crops with high yield potential and low soil nitrogen levels that grow under warm temperatures, high-pH soils, with urea fertilizers, surface application, and heavy crop residue. These target crops include tomatoes, lettuce, melons, corn and small grains. Citrus tree crops and pastures may also receive priority for studies due to high N fertilizer requirements.

The soils from which we would to begin pilot sampling of NH_3 emissions are generally well-drained loamy sands to fine sandy loams of the Hanford association in the granitic alluvial plains of the Eastside Valley (Huntington, 1971). Particle size distributions are typically reported as 60% sand, 32% silt, and 8% clay, with bulk density of around 1.8 g cc^{-1}. Organic carbon content is low at about 0.44% in surface layers, with a C-to-N ratio of 11. Soil pH is typically near neutral, although variability is high. Wind speeds recorded at the CIMIS weather station on the CSUF campus range from 1 to 5 m s^{-1} with a 15-year average of about 2.5 m s^{-1} over the summer growing season (May- August). Cropping systems that are readily available for field measurements include field vegetables, orchards and vineyards, which receive dissolved fertilizer (typically ammonium nitrate) in irrigation treatments routinely during the crop growing season. Actual field measurements made by our group would be preceded by a training schedule developed for student assistant(s) from CSUF. Laboratory space on the CSUF campus is available for all required analytical work and sample preparation.

Phase 2. Summer-Fall - Organic sources of NH_3 before and after application.

In testing the mass balance technique for organic-source gas emissions, we would also target fields in the CSUF area that receive spread application of organic fertilizer by-products from dairy and livestock production in the Central Valley. In our estimation, the most significant type of animal

operation in the San Joaquin Valley is milk production. Dairies throughout Kings and Tulare counties typically feed their cows a high N ration. Bovine urine and feces may represent potential sources for NH_3 emission. Where poultry operations exist, they too could be significant NH_3 sources. However, for this study, NH_3 emission rates will not be measured during stages of animal housing, manure storage, slurry digestion, but only during and after field application (as solid matter or diluted in irrigation waters) to nearby croplands.

<u>Supplemental sampling and other support from CE-CERT, UC Riverside</u>

Ammonia Flux Measurements in Support of the CSU-NASA Proposal to the ARB

Denuders consisting of a fabric material coated with phosphoric acid to collect ammonia (Fitz, 1996; Fitz and Tuazon, 1997) will be used to passively sample ammonia. The flux monitoring design is based on the approach described by Schjoerring (1995), but instead of denuder tubes, tubes holding fabric denuders are used. A pair of fabric denuders is installed in an open-face, open outlet Savillex Teflon filter holder. An adapter is used to attach the holder to a section of 11/2 in PVC pipe. The other end of the PVC pipe is fitted with a similar pair of denuders. Sample collection depends on the wind flowing through the assembly. The amount of ammonia collected is therefore proportional to the wind speed, direction, and ammonia concentration. If the wind is normal to the tube, no significant amount of ammonia would be collected. In order to measure the flux at a point, two such samplers are needed; one on an east-west axis, the other on a north-south axis.

To determine the net ammonia flux from the test plot the ammonia flux upwind will be determined in addition to the downwind flux at four elevations up to 20m.

Scope of Work:
We will provide six sets of passive flux samplers (one will be used to provide collocated samples). Each sampler consists of two PVC pipe mounted perpendicularly. Each pipe has a Savillex filter holder attached to each end. We will also provide one active sampler for determining ammonia concentration at one sampling position downwind. A total of 400 phosphoric acid coated denuders will be prepared. We will bring the sampling equipment to the Fresno site and train the site operators. Site operators will be provided without charge to CE-CERT. Log sheets and equipment to minimize contamination during the sampling procedure will also be provided. The sampling substrates need to be stored under refrigeration. At the end of each seasonal sampling episode, site operators will ship the sampled substrates back to CE-CERT. The equipment will also be shipped back to CE-CERT at the end of the study. Shipping cost are not covered in the CE-CERT budget.

The exact sampling schedule will be determined later, but will include no more than 370 denuder substrates to be analyzed for ammonium. A potential scenario for one crop is as follows:
5 samples/period (one upwind four downwind, a total of 40 substrates)
2 periods/day
2 days/episode
2 episodes/project

The total number of substrates per flux sampling episode would therefore be 160, for a total of 320 for the project. Adding 16 collocated substrates for the flux sampler, 8 pairs of substrates for the active sampler and 16 dynamic blanks (8/episode) for a total of 360 denuder substrates to analyze. Other scenarios can be used to extend the number of plots or days sampled per plot. If the wind direction is constant, then a single tube with one denuder holder can be aimed directly into the wind. This will increase the number of sampling periods four fold. If the denuders collect less than 200 (g of

ammonium, then breakthrough is unlikely and only the front denuder is needed. While this also has the potential of a four-fold reduction in the number of samples to analyze per period, the amount collect is a function of both wind speed and concentration. The amount of ammonium collected is therefore difficult to predict at the time of sampling since no direct reading ammonia monitors are proposed for this study. This approach may be useful for the second or third day of sampling after fertilizer application. We can also adjust the number of samples collected per day (three maximum), the days of sampling, and the number of crops.

The phosphoric acid coated ones will be extracted with deionized water. As with the coating process, the extractions will be conducted in a laminar flow hood to minimize contamination. The concentration of the extract will be analyzed using the indophenol blue method (Scheiner, 1976). For the passive flux denuder, extract volume, exposed denuder surface area and sampling time will be used to calculate the ammonia flux in units of (g hr-1 m-2. Extract volume, sampling time and flow rate will be used to determine ammonia concentrations from the active sampler in units of (g gm-3. The concentration and averaged wind data will also be used to determine the flux at a single point.

Quality Control will consist of calibrating the flow of the active sampler during installation. Flow checks will be made at the beginning and end of each sampling period. Precision of the passive flux sampler will be calculated from collocated samples and minimum detection limit by the variability of the blank values. Denuder efficiency will be calculated each sampling interval using the amounts collected on the denuders in series.

Task 3. Ammonia Emission Modeling

Based on available flux measurements, we are prepared to refine and apply our recently developed computer simulation algorithm (Equation 1) to predict NH_3 volatilization flux (A) from chemically fertilized soils of the Central Valley. Our algorithm is built as a function of fertilizer type (FT) and application method (AP) of the applied ammonium concentration (N_a; g N m^{-2}), modified by scalars (multipliers ranging from 0-1) for a soil surface temperature (Ts ^{o}C) dependent pH response (Figure 1) and soil moisture content. Equation 1 is derived from reports by Denmead et al. (1982) and the National Research Council *Subcommittee on Ammonia* (1979). It includes a scalar term for a maximum rate of volatilization (k_A) which will be initially is set at value of 0.5 (Schlesinger and Hartley, 1992). Adjustments can be made in order to most closely simulate observed NH_3 volatilization flux rates.

$$A = N_{a(FT, AP)} \, k_A \, \{1/[1 + 10^{(0.09018 + 2729.92/(273.16+Ts) - pH)}]\} \, (1-M_s) \qquad (1)$$
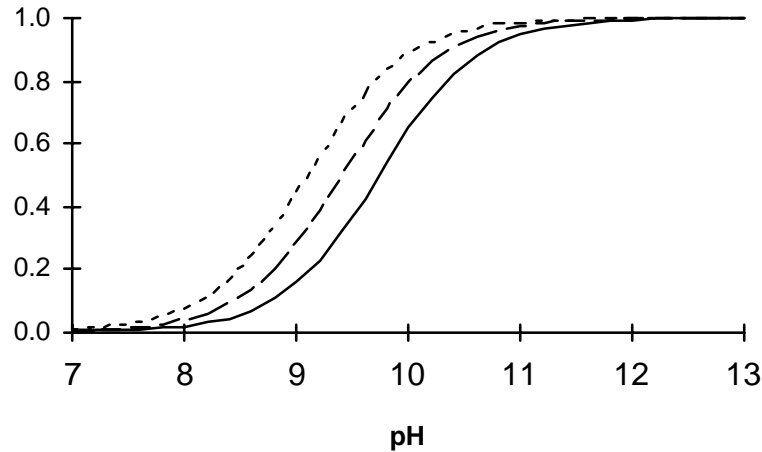

Figure 1. Temperature-dependent scalar for the effect of soil pH on volatilization of ammonia. Dotted line (30° C), Dashed line (20° C), Solid line (10° C). After Denmead et al. (1982).

To further account for the effect of aqueous transport of applied fertilizer through moist soil layers in the model, a texture-dependent scalar (M_s) is defined below for potential water extraction as a function of percent volumetric soil moisture content (Θ; m m^{-1}). In this context, the M_s scalar is intended to represent the influence of soil moisture conditions on fertilizer N transport through the soil, where *a* and *b* are texture-dependent empirical coefficients (defined as in Saxton et al., 1986).

$$M_s = (1 + a) / (1 + a \, \Theta^b) \qquad (2)$$

Soil temperature and moisture content at any study site will be simulated using local weather station data to drive the NASA-CASA model (Potter et al., 1997; Frolking et al., submitted). This well-tested simulation model for natural and agricultural systems uses a layered soil profile design for heat and moisture fluxes. The plant and soil chemical component of the NASA-CASA model simulates carbon-nitrogen cycling, nutrient uptake by crops, and associated flux of N trace gases to the atmosphere using a set of compartmental difference equations with a structure comparable to the CENTURY ecosystem model (Parton et al., 1992). First-order equations simulate exchanges of decomposing plant residue (metabolic and structural fractions) at the soil surface, together with surface soil organic matter (SOM) fractions that presumably vary in age and chemical composition. Active (microbial biomass and

labile substrates), slow (chemically protected), and passive (physically protected) fractions of the SOM are represented. Effects of cultivation and N fertilization of the soil have been tested in regional analyses of the NASA-CASA model (Davidson et al., 1998).

To address management effects, several new model scalars (unitless multipliers) will be developed to represent soil fertilizer N modifications of potential gas emitting reactions. Fertilizer type (FT) effects are based on the hypothesized changes in rates of nitrogen oxidizing reactions. For example, use of anhydrous ammonium and ammonium types should slow the rate of oxidation, relative to urea and nitrate application. In addition, we would evaluate whether subsurface fertilizer application methods (FA) retard nitrification reactions relative to surface methods. Each scalar will be tested to interpret how ammonia emission fluxes can be predicted in a manner consistent with field observations.

Modeling of ammonia emission fluxes from storage and field application of by-products from dairy and livestock production can be developed within our existing system based on a "whole-farm" modeling approach (Hutchings et al., 1996). The model structure will be adapted to track nitrogen input as animal feed until N is lost as ammonia emission flux from fields where organic fertilizers, slurries, or urine products are applied (Figure 2).
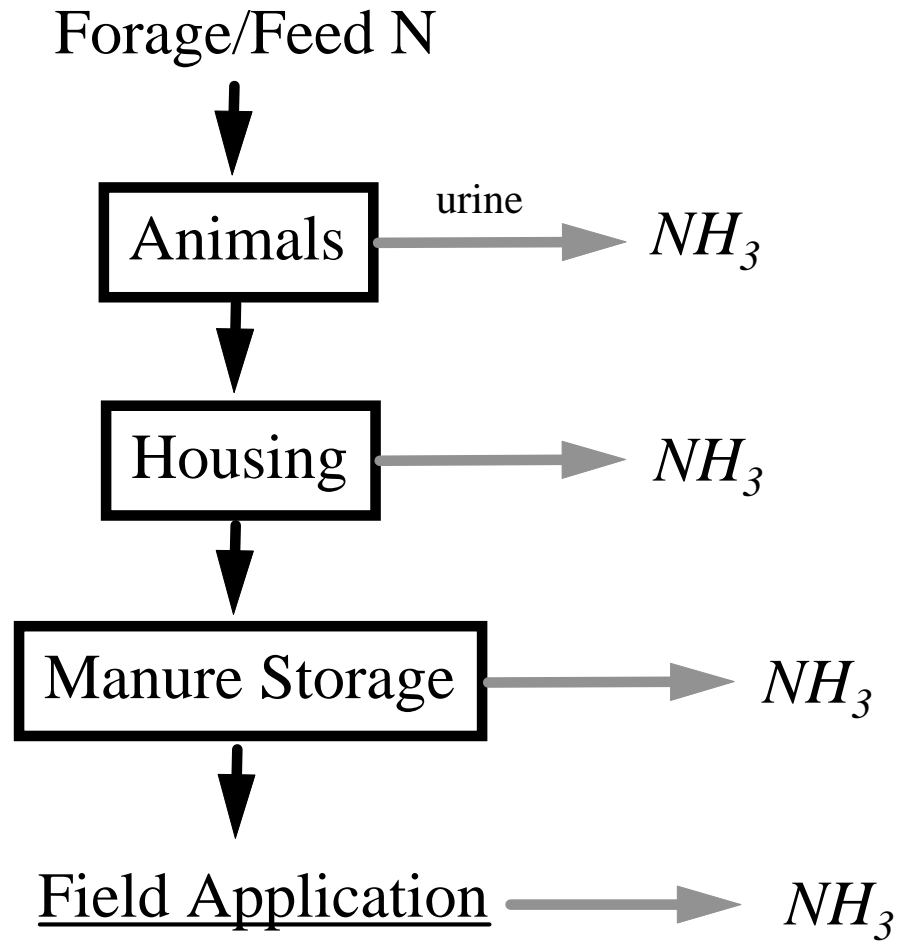
Forage/Feed N

Animals ——urine——▶ NH_3

Housing ——▶ NH_3

Manure Storage ——▶ NH_3

Field Application ——▶ NH_3

Figure 2. Major routes for nitrogen flow in the farm animal model component for NH_3 emission (adapted from Hutchings et al., 1996).

Task 4. Regional Extrapolation-Simulation Approach

Our NASA-CSU research team has previously published an unique regional extrapolation technique for estimating emissions inventories for soil trace gases (Davidson et al., 1998). This technique is built on the foundation of a state-wide geographic information system (GIS). The GIS requires geographically and temporally consistent data layers for land use types, vegetation-livestock grazing-crop cover types, fertilizer application rates, farm animal stocking rates, soil properties, climate variables, and satellite remote sensing products (such as the seasonal greenness index). An example of crop cover data layers is shown in Figure 3 from our GIS.

For extrapolation of simulated and measured NH_3 volatilization fluxes, potentially with inventories of other reactive trace gases (NO_x) from biogenic sources, we will combine the plot- and farm-level computer models (described above) with gridded GIS data layers to generate state-wide gas inventory estimates at a monthly (or daily) time step. Hourly emissions could be interpolated from these inventory estimates. Our nominal spatial resolution for the inventory estimates would be 1-km, although higher resolution estimates may be feasible, depending on the innovative use of State Department of Water Resources (DWR) crop type GIS layers.

The following parameter data sets and look-up tables will be further developed to serve as inputs and linkages to our state-wide GIS modeling system for NH_3 emission estimates:

Daily climate (surface temperature, rainfall, radiation, humidity)
Irrigation schedule in frequency (applications per week) and amount (cm per hectare)
Irrigation type (sprinkler, gravity, micro, etc.)
Fertilizer use (chemical form, amount [kg/ha], and frequency of applications
Day/Month of seed sowing
Day/Month of peak green leaf cover
Day/Month of crop harvest
Crop:shoot:root biomass ratio (kg:kg:kg at harvest)
Dry matter (kg/ha) of aboveground green biomass
N contents (%) of aboveground green biomass
Rooting depth (cm)
Tillage type
Nitrogen content of animal feed supply per farm type
Amount of feed consumed per animal per farm type
Apparent digestibility of animal feed type
Rate of animal body weight gain
Milk yield per animal type
Average number of animals per farm type

For gridded specification of many of these model parameters at the localized farm level, the California DWR land cover in our GIS data base contains multiple categories for both conventional agricultural systems [e.g., grain and hay crops (6 types), rice, field crops (12 types), pasture (7 types), truck crops (25 types), fruits and nut crops (24 types), and vineyards], plus animal-agricultural systems [e.g., farmsteads , livestock feed lots, dairies, and poultry farms].

Total Budget Summary

Direct Costs

A. Field Measurements	**$102,827**
B. Data Assimilation, Modeling and GIS Analysis	**$45,456**
C. Additional Field Sampling by CE-CERT	**$13,731**
Total Direct Costs	**$162,014**

Indirect Costs

A. Field Measurements	**$16,373**
B. Data Assimilation, Modeling and GIS Analysis	**$6,771**
C. Additional Field Sampling by CE-CERT	**$1,267**
Total Indirect Costs	**$24,411**

Total Budget Requested	**$186,425**

Schedule of Project Milestones

April 1999
 Order field instruments and equipment
 Order California data sets for climate and fertilizer rates
 Evaluate potential field sampling sites and major crop types

end May 1999
 Assemble state-wide geographic information system (GIS)
 Evaluate data quality of GIS layers
 Hire CSUF students

end June 1999
 Complete tests of ammonia flux model for agricultural field sites
 Submit literature review report to CARB
 Take delivery of field instruments and equipment

end July 1999
 Install field instruments and equipment
 Train CSUF students and/or technicians

end October 1999
 Evaluate Phase 1 set of ammonia flux estimates
 Submit preliminary report to ARB
 Implement "whole-farm" modeling approach

end December 1999
 Evaluate Phase 2 of ammonia flux estimates
 Complete tests of ammonia flux model for state-wide GIS

end March 2000
 Submit draft report to ARB

end June 2000
 Submit final report to ARB

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PROPOSAL COVER SHEET

Proposal To:

     California Air Resources Board
     Technical Support Division
     2020 L Street
     Sacramento, CA 95814
     attn: Patrick Gaffney

Submitting Organization:

     Center for Irrigation Technology
     School of Agricultural Sciences and Technology
     California State University - Fresno
     Fresno, CA 93740-0018

Title of Proposed Research:

     Development of Emissions Inventories for Ammonia in Agricultural Systems of California

Total Amount Requested:	Proposed Duration:	Desired Starting Date:
$186,425	12 months	January 1, 1999

Principle Investigators:

Charles Krauter	CSU Fresno
Steven Klooster	CSU Monterey Bay

Project Cooperators:

Christopher Potter	NASA Ames Research Center, Moffett Field, CA
Dennis Fitz	Center for Environmental Research, UC Riverside, CA

Payments to:

     Grants and Research Office
     CSU Fresno Foundation
     4910 North Chestnut Ave.
     Fresno, CA 93726-1852
     Phone: (559) 278-0850
     FAX: (559) 278-0992

Send Award Notice to:

     Dr. David Zoldoske, Director
     Center for Irrigation Technology
     California Agricultural Technology Institute
     CSU Fresno
     Fresno, CA 93740-0018
     Phone: (559)

(CSU Fresno authorization signatures attached on Project Information Form)

Project longer than 1-year justification

This project includes two phases of field testing – a springtime component, and a fall component. The project is scheduled to begin in the Spring of 1999. Because of the time necessary to evaluate and perform modeling analysis on the Fall data, the project cannot be fully completed within a one-year time frame. Instead, fifteen months are required to meet the project objectives.